Rachel Cox

Mechanical Engineer & Project Manager

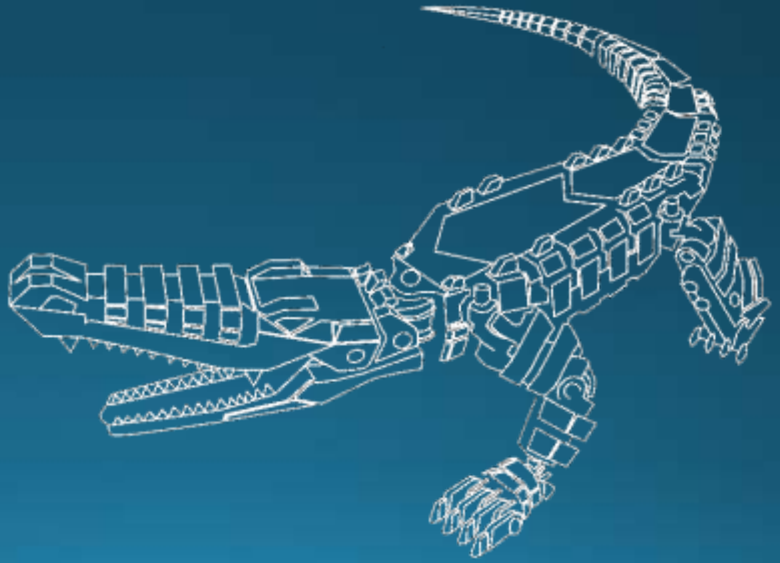
NASA Swamp Works at Kennedy Space Center

SPACE RESOURCE TECHNOLOGIES

Image Credit: NASA/KSC

WHO WE ARE AND WHAT WE DO

SWAMP WORKS



Swamp Works is an Innovation Environment

that strives to use rapid, lean, cost effective approaches.

- High bay lab area
- Technology incubator area – spaces for new project ideas to grow
- Lunar Regolith (moon dirt) Test Bin
- Machine Shop
- Innovation Space – loft area with white boards for brainstorming
- Outdoor rock yard for testing robots

Simulated Moon Hazard Field


Shuttle
Landing
Runway
aerial view

AREAS OF FOCUS

Our mission is to provide government and commercial space ventures with the technologies they need for working and living on the surfaces of the Moon, planets, and other bodies in our solar system.

We have six labs with different focus areas.

Granular Mechanics and Regolith Operations

Development of technologies for working with regolith (surface material) on other bodies in space and studying their basic physics and geology.

Applied Chemistry

Chemical solutions for in situ resource utilization, leak detection, precision cleaning, oxygen recovery, environmental remediation, and more.

Electrostatics and Surface Physics

Investigation of electrostatics and surface physics with applications for spaceflight and planetary exploration. Detecting and preventing electrostatic discharge.

Advanced Materials and Systems

Polymer science, materials chemistry, and novel composite systems for space applications. Technologies include, among others, aerogel composites, smart thermal materials, chemochromatic gas sensing materials, and carbon nanotube and conductive polymers.

Applied Physics

Development of instrumentation, sensors, and tools for spaceport ground processing on Earth and for in situ space resource utilization on the moon and Mars.

Corrosion Technology

Applied research and testing for all areas of corrosion, including material performance and degradation in various environments, and new corrosion detection and control technologies.

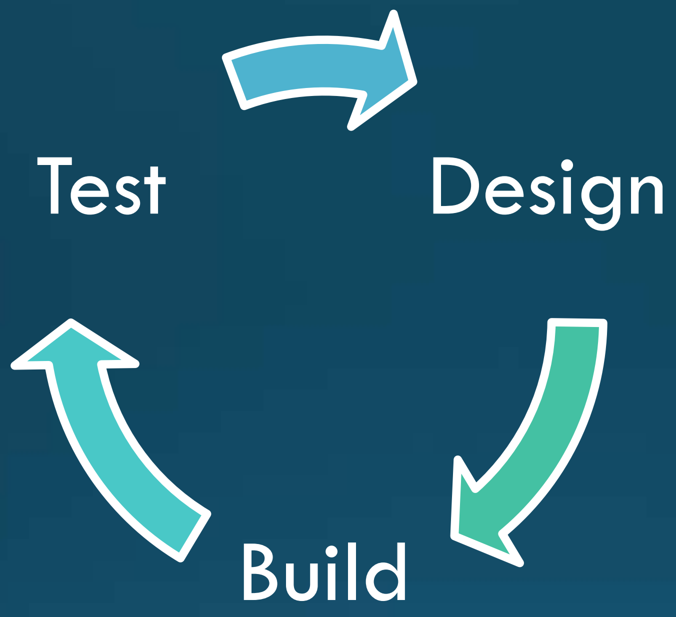
TECHNOLOGY READINESS

NASA has a scale to measure how far along a technology is in its development lifecycle. They call increments on the scale Technology Readiness Levels, or TRLs.

Swamp Works focuses on TRLs 1-5, with the occasional 6.

1. Transition from scientific research to applied research
2. Applied research
3. Proof-of-concept validation
4. Standalone prototyping implementation and test
5. Thorough prototype testing in relevant environment
6. Prototyping on full-scale realistic problems
7. System functions in operational environment
8. System completed and “mission qualified”
9. Mission/ground operations

Design-build-test conducted iteratively with increasing knowledge of the operating environment will result in an end product that optimizes safety and performance.



Begin with a clear vision of what the technology will do and won't do

By the Preliminary Design Review (PDR), we will know exactly what we want, how we're going to build it, and how we're going to operate it

Functional Requirements	Expanded Functional Requirements	Preliminary Design Requirements	Flight Design Requirements
Gen I	Gen II	Gen III	Flight

Credit: Astronaut Mike Gernhardt, NASA JSC

SELECT PROJECTS

SPACE TECHNOLOGY PORTFOLIO

RECYCLING: TRASH TO GAS

During the course of a year in space – one half the length of time a mission to Mars is expected to take – trash processing for a crew of four would create about 2,200 pounds of methane fuel, enough to power a launch from the lunar surface.

Trash could be a valuable resource on long-duration missions. Food wrappers, used clothing, scraps, tape, packaging and other garbage accumulated by a crew of four astronauts flying beyond low Earth orbit could be turned into valuable methane gas, oxygen and even water using processes and much smaller versions of devices that are already doing the same thing on Earth. Source: www.nasa.gov/centers/kennedy/about/sustainability/trashtogas.html

Image Credit: NASA/Dmitri Gerondidakis

Image Credit: NASA/Dmitri Gerondidakis

IN-SITU RESOURCE UTILIZATION

LIVING OFF THE LAND ...IN SPACE

Like explorers before us, we don't need to carry everything with us. In-situ resource utilization, or ISRU, is the idea of harnessing resources available at our destination, whether it is Mars, the Moon, an asteroid, or elsewhere.

Why does NASA need ISRU?

- Launch costs (~$4,000/kg)
- Payload volume does not allow enough space and mass to send supplies, return propellants and equipment

What are the unique challenges?

- Various surface conditions
- Reduced gravity
- Extreme temperatures
- Hard ice

“ The absolute least efficient way to get air, water, and fuel into space is the way that we currently do it: by packing as much of it as we can into rockets on Earth, and then firing it off into orbit. If this is how we have to get supplies to the moon, or Mars, it's going to be ludicrously expensive and time consuming. ”

Evan Ackerman, IEEE

Source: **NASA Training 'Swarmie' Robots for Space Mining.**

http://spectrum.ieee.org/automaton/robotics/military-robots/nasa-training-swarmie-robots-for-space-mining

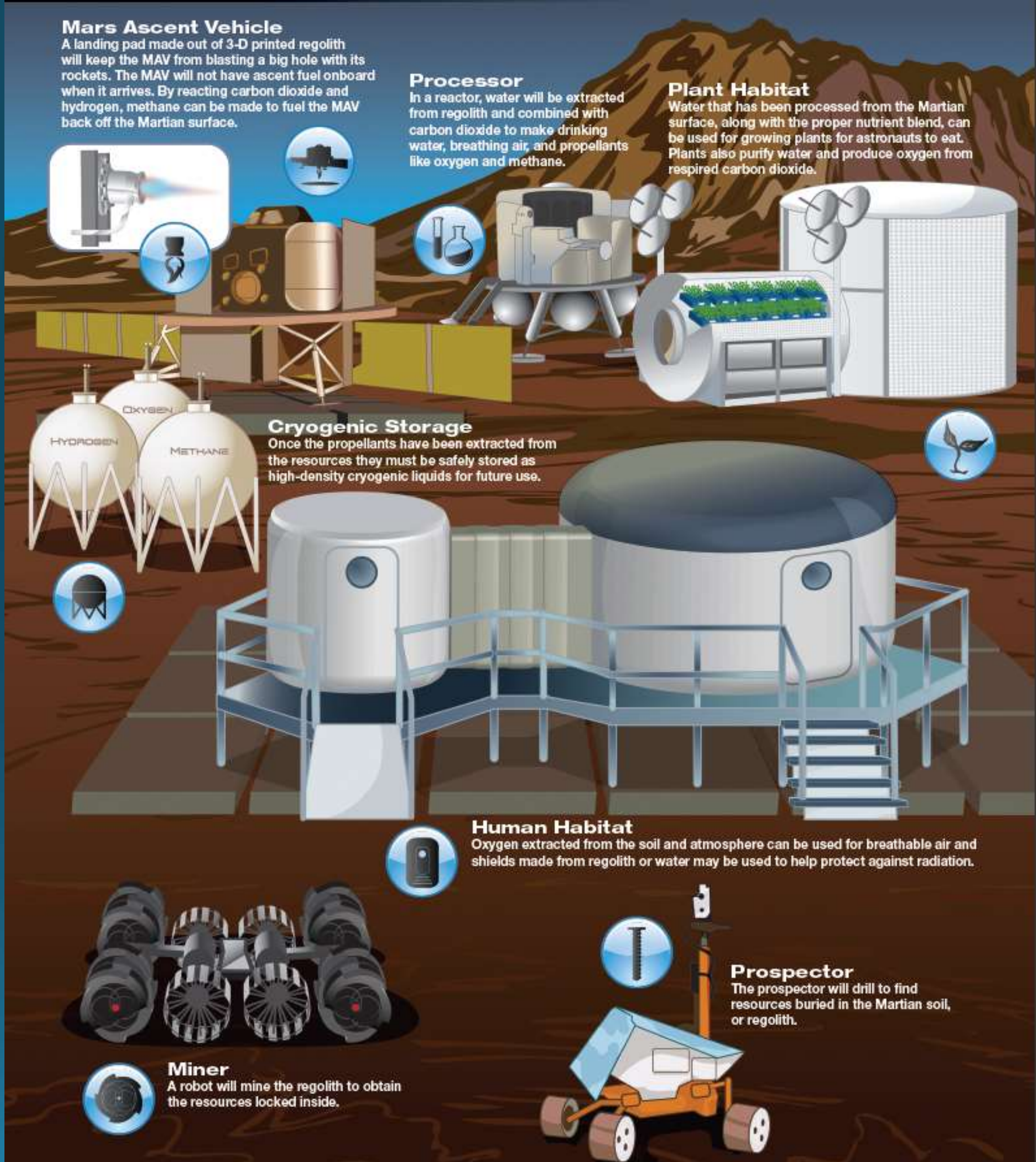
DEVELOPING THE TOOLS TO MEET THE CHALLENGES

Potential sites for ISRU

- Moon
- Mars and its moons
- Asteroids
- All other solar system bodies

CO_2 from the Mars Atmosphere

- Water from the soil
- Permafrost
- Hydrated minerals in soils
- Buried Glaciers

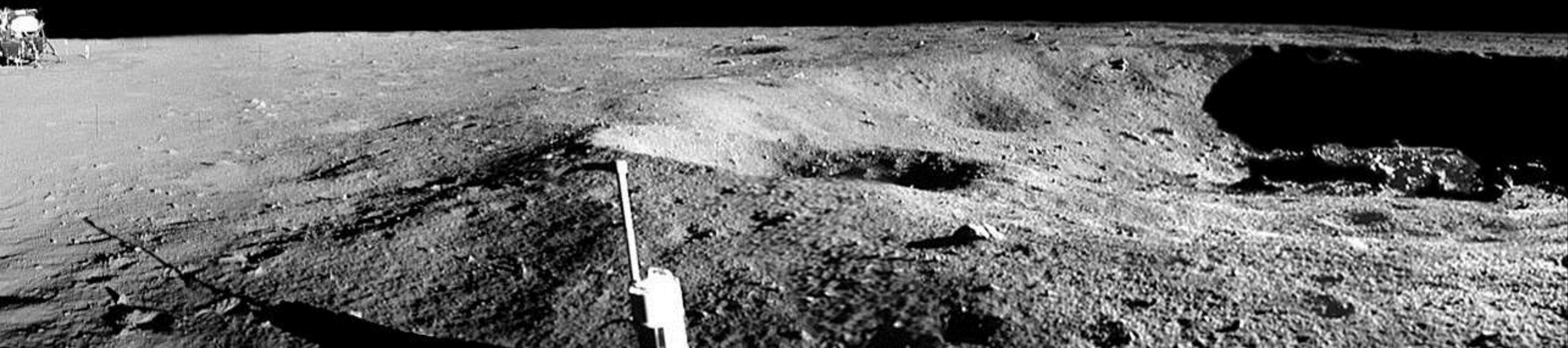


REGOLITH AS A RESOURCE

Regolith is the surface layer of loose material that sits on top of bedrock. It includes all the rocks, gravel, and dust – from large boulders to tiny particles. It exists on Earth, other planets, moons, and asteroids.

Swamp Works is exploring ways to exploit the regolith for as many uses as possible. We take one of two approaches:

1. Extracting resources out of the regolith, usually with chemical processes
2. Using the regolith as a raw material for building structures

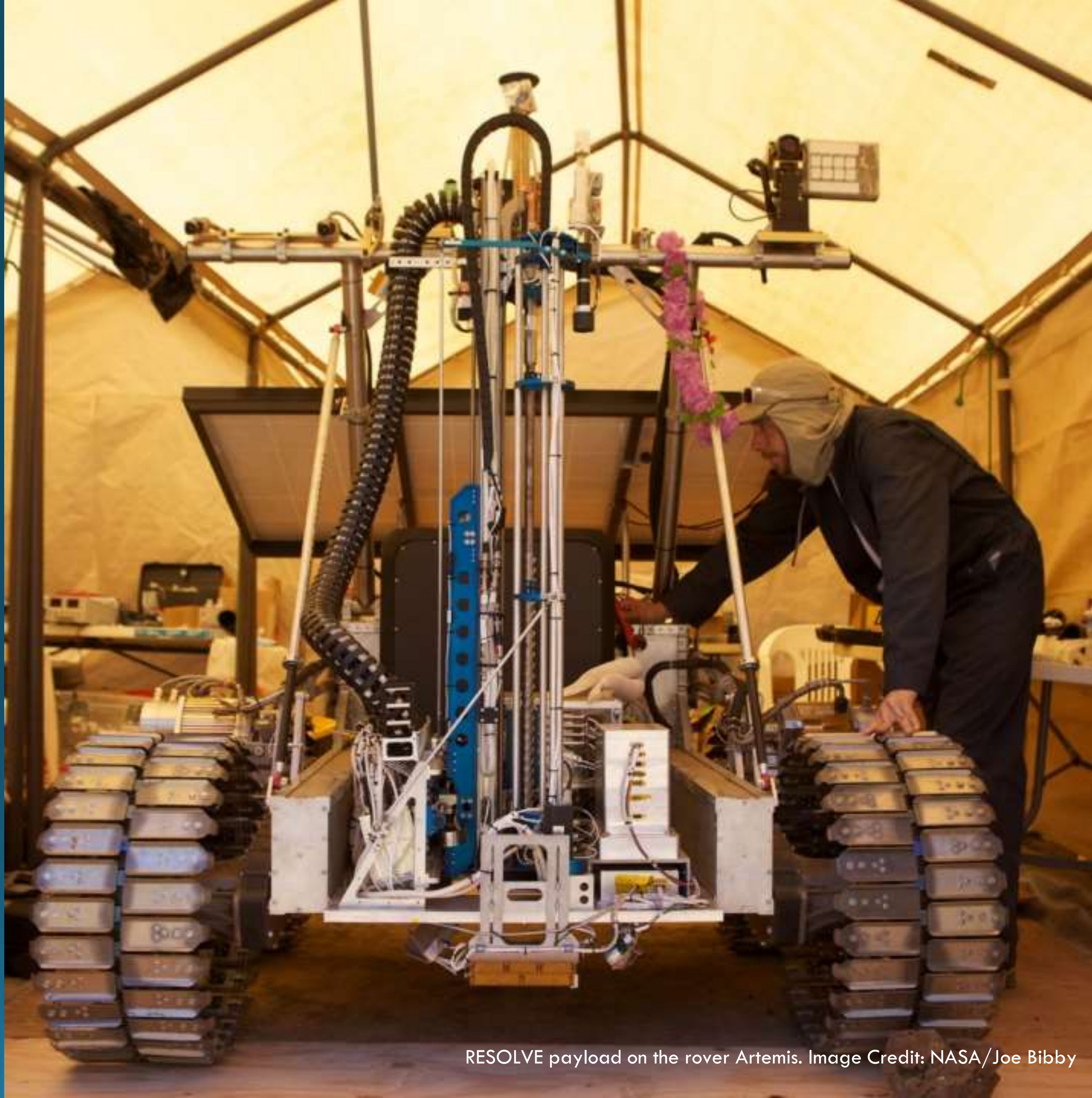


PROSPECTING AT LUNAR POLES

This scientific instrument suite called RESOLVE (short for Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction) will prospect for water ice on the moon as the primary payload on the Resource Prospector (RP) mission planned to launch in the early 2020s.

RESOLVE instruments:

- A neutron spectrometer and near infra-red spectrometer for selecting sample sites
- A drill and core transfer mechanism for sampling
- A heating oven for processing the sample
- A gas chromatograph/mass spectrometer to quantify water and other volatiles



RESOLVE payload on the rover Artemis. Image Credit: NASA/Joe Bibby

RP-15

RESOLVE has conducted 4 analog missions to demonstrate enhancements in technology capability.

The latest analog mission, RP-15, was dubbed a "mission-in-a-year". The RP-15 prototype rover and RESOLVE payload system were developed in just 12 months, fully capable of prospecting, drilling, and processing materials here on Earth, similar to how RP plans to operate on the moon.

RP Capabilities:

- Mapping the lunar surface
- Entering permanent shadows
- Exposing and analyzing subsurface regolith
- Capturing and heating regolith
- Identifying the volatiles

The RP rover team installs the drill on the RP-15 Ground Test Unit. Image Credit: NASA

RESOLVE payload on JSC rover during RP-15. Image Credit: NASA

RESOLVE payload on JSC rover during RP-15. Image Credit: NASA

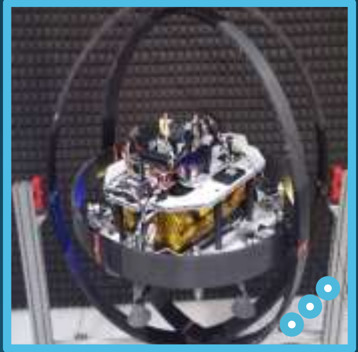
ALTIP PROJECT

Swamp Works is developing an autonomous robotic flying platform that could be used for sampling for resources in environments such as permanently shadowed lunar craters (expected to contain water ice) and Martian lava tubes (for shelter or resources).

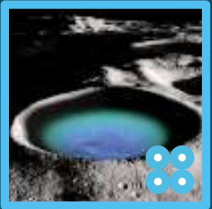
ALTIP would scout out regions of interest using its own navigation, hazard avoidance, and sampling tools.

ALTIP concept

Artist concept of ALTIP in Martian lava tube



ALTIP on gimbal for gravity offload testing



Permanently shadowed lunar crater region

MARCO POLO

Mars **A**tmosphere and **R**egolith **CO**llector/**P**r**O**cessor for **L**ander **O**perations (MARCO POLO) project was established to build and demonstrate a methane/oxygen propellant production system in a Mars analog environment.

The MARCO POLO project will provide a demonstration platform for all aspects of Martian soil and atmospheric processing, beginning with the extraction of water from Martian soil, which would then be electrolyzed into hydrogen (H_2) and oxygen (O_2), and the capture of carbon dioxide (CO_2) from the Martian atmosphere to produce methane (CH_4) using H_2 from the water.

Source:
https://www.researchgate.net/profile/Anthony_Muscatello/publication/280091306_Atmospheric_Processing_Module_for_Mars_Propellant_Production

KSC: Mockup Lander w/Hopper, Mock Oven, and APM Simulator in Regolith Bin

KSC: RASSOR 2.0 Excavator Rover

KSC: Common Bulkhead Cryotank

JSC: Soil Processing Module

KSC/JSC: Water Cleanup Module

JSC: Water Processing Module (Electrolyzer)

KSC: Atmospheric Processing Module

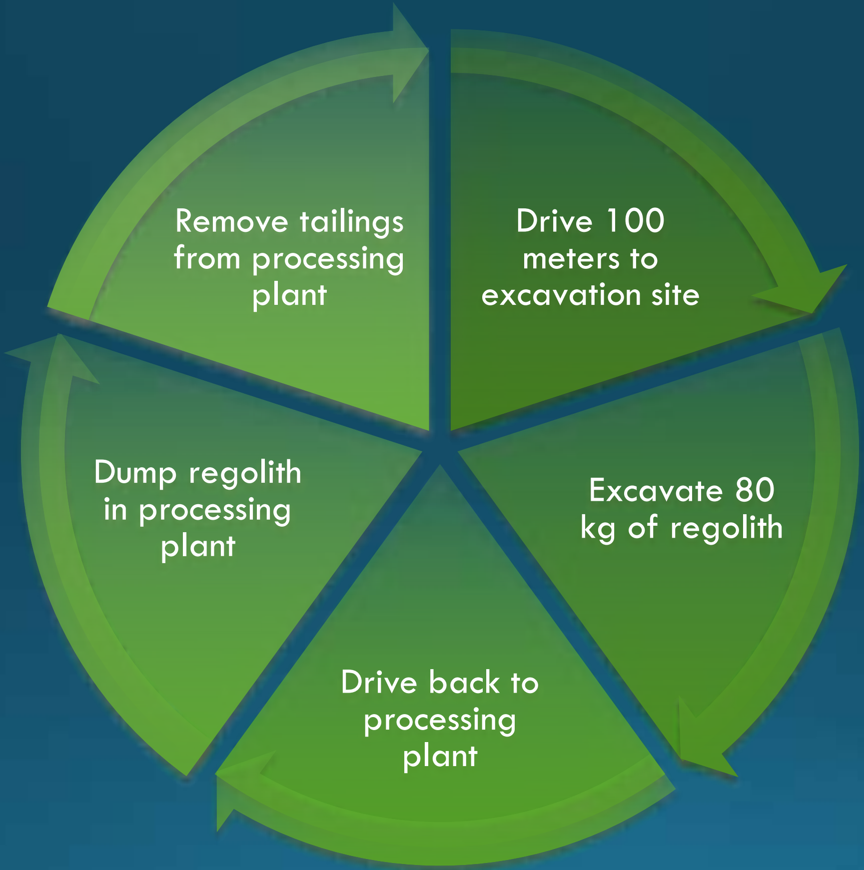
Photos of MARCO POLO Modules at KSC and JSC
(Image Credit: NASA KSC)

MARS ISRU EXCAVATION: RASSOR

Features:

- Dual counter rotating bucket drums for canceling horizontal excavation forces
- Low mass (66 kg)
- 80 kg payload capacity per excavation cycle
- 0.25 m/s driving velocity
- Obstacle detection, avoidance, and traversing
- 0.377 $kg/(kg/hr)$ $((Vehicle\ mass)/((delivered\ regolith)/hr))$ TA 7.1.2.5 Goal: < 2 $kg/(kg/hr)$ $((Vehicle\ mass)/((delivered\ regolith)/hr))$
- 0.610 $W/(kg/hr)$ $(Power/((delivered\ regolith)/hr))$ TA 7.1.2.5 Goal: < 7.0 $W/(kg/hr)$ $(Power/((delivered\ regolith)/hr))$

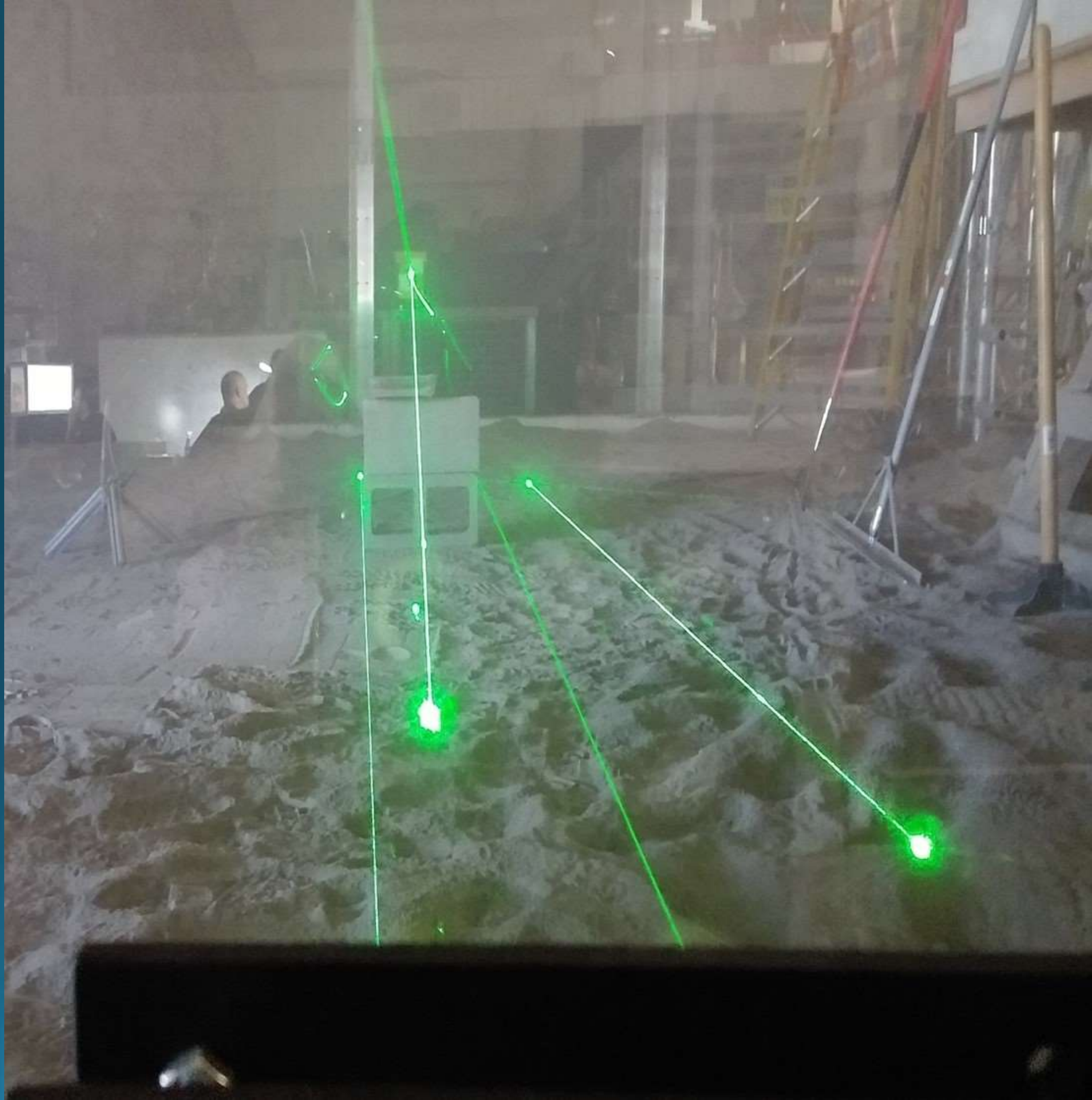
RASSOR: CONCEPT OF OPERATIONS

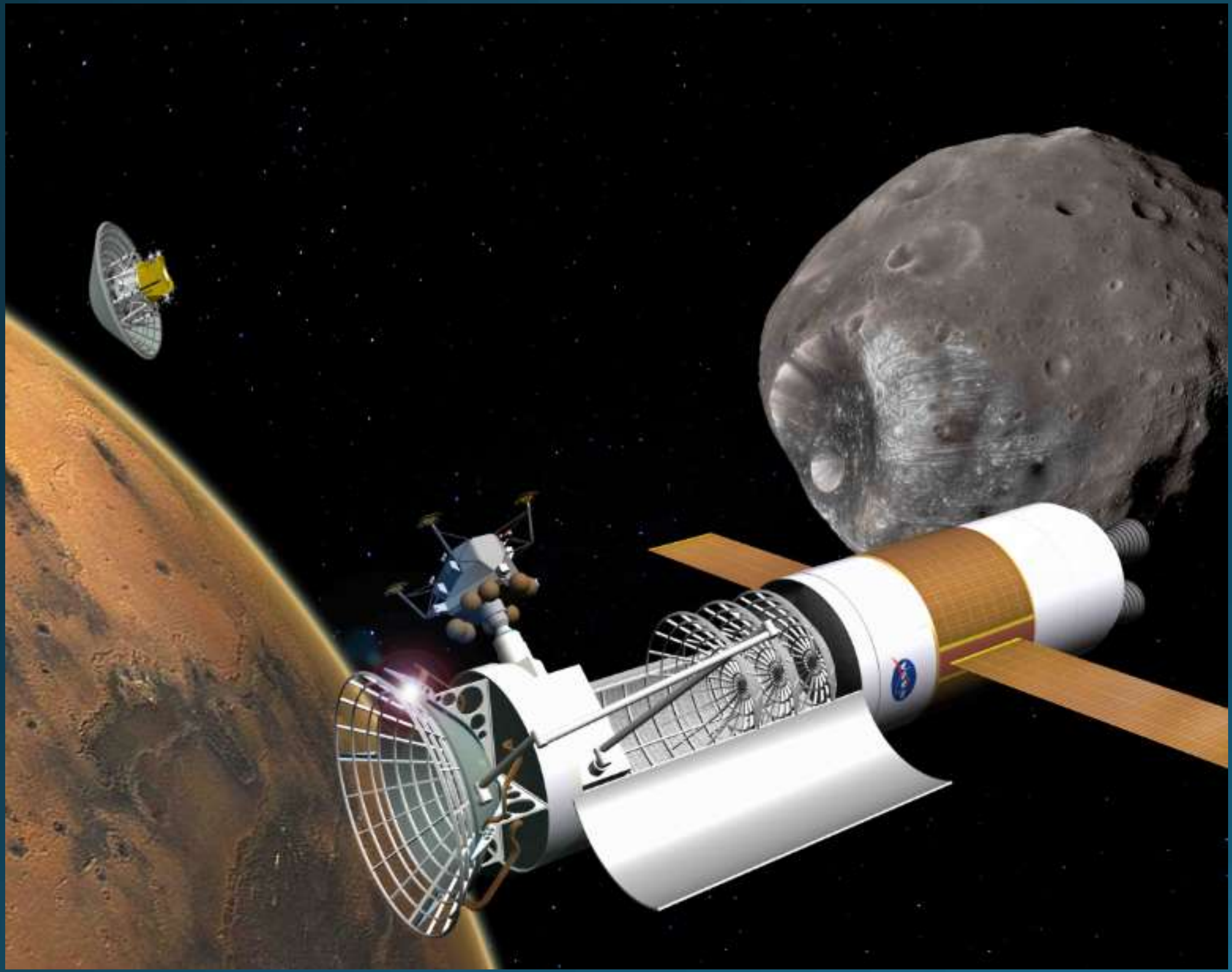


LOW VISIBILITY MINING IN LOW/ZERO GRAVITY

Levitated dust on the moon/asteroids and dust storms on Mars will pose challenges to visibility during mining operations. Low illumination and low-angle-of-incidence lighting pose significant problems to computer vision and human perception.

Swamp Works is testing and studying the effect of dust and the difficult lighting conditions on telerobotic perception systems and sensors to better assess and refine regolith operations for these missions.



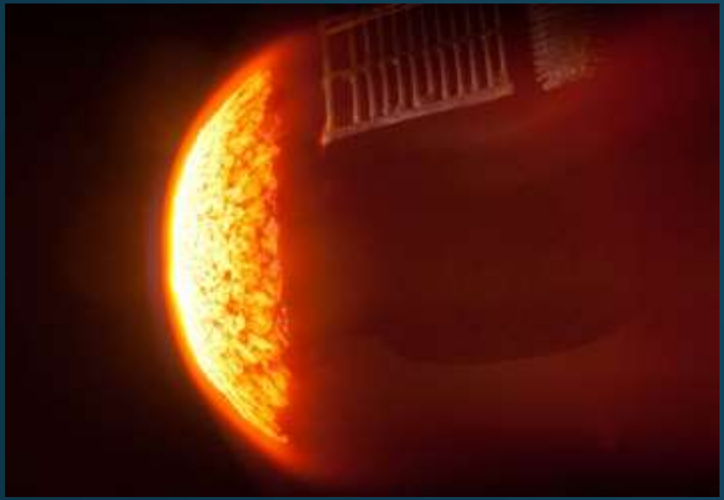


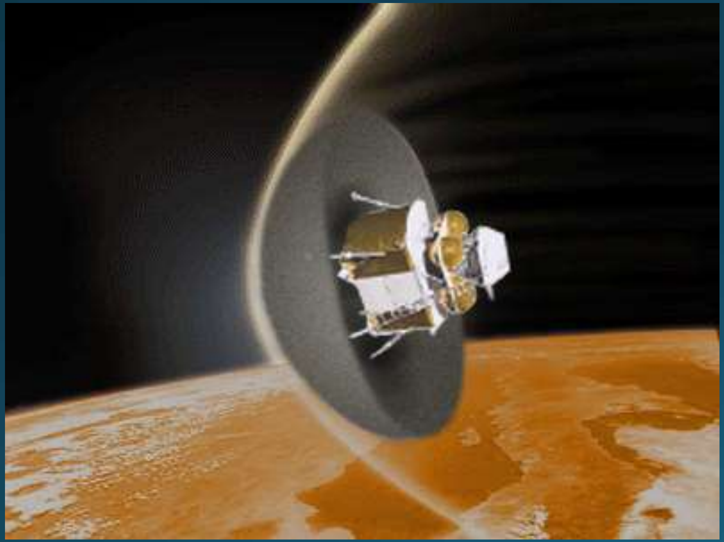
Artist concept of heat shield fabrication. NASA/KSC

REGOLITH HEAT SHIELDS

When spacecraft enter an atmosphere, like when landing on Mars or upon returning to Earth, the atmosphere creates a high amount of friction and heat on the fast-moving vehicle. If the vehicle did not have thermal protection, it would burn up upon (re)entry.

Heat shields are very heavy and therefore costly to launch from the gravity well of Earth. Fabricating heat shields in space, like shown in the concept to the right, could make the missions more affordable.

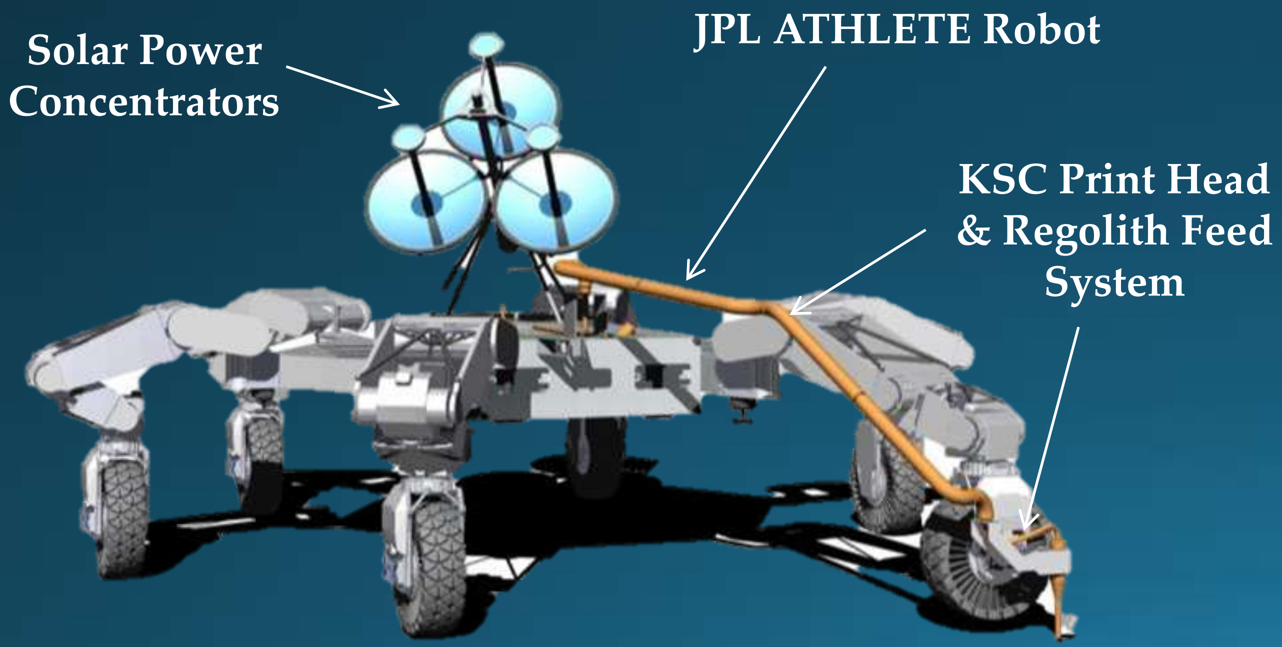




Clockwise from top left: Regolith-derived heat shield sample undergoing flame testing; regolith samples post-test; artist concept. Image Credit: NASA/KSC

REGOLITH 3D PRINTING ("ADDITIVE MANUFACTURING")

Swamp Works is investigating methods of using robotic construction technologies to build structures using Lunar and Marian regolith.



REGOLITH 3D PRINTING/ADDITIVE MANUFACTURING

One method of 3-D printing involves sintering – heating the regolith to just-below-melting temperatures (1200-1500 °C), making the dirt stick together and form a brick-like material. Robotic 3D printers can then build walls of a habitat.

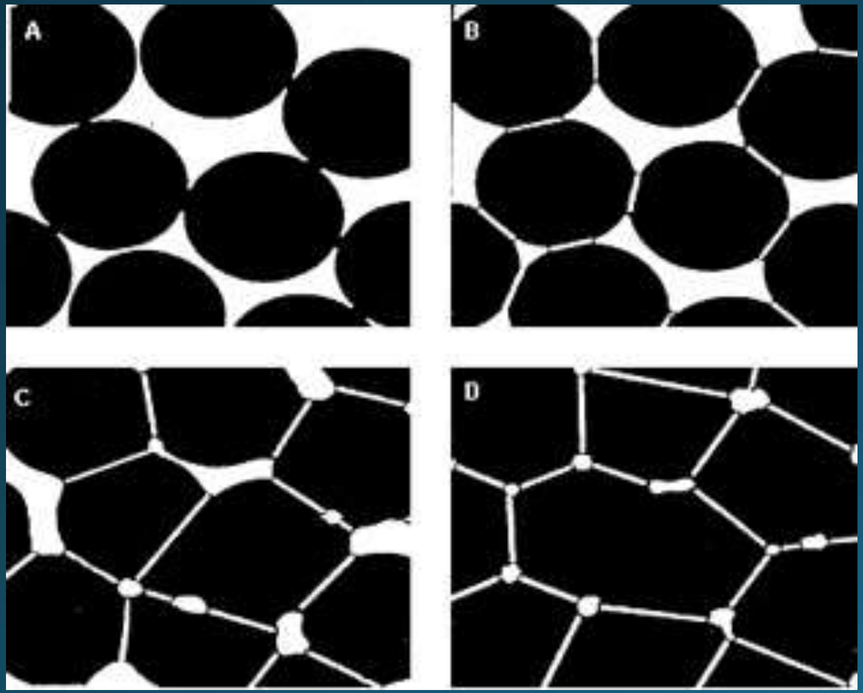
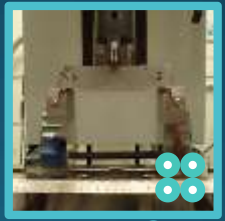


Image credit: Contour Crafting

3D PRINTING WITH REGOLITH AND POLYETHYLENE

Swamp Works is currently designed a prototype print head to prove the concept of 3D printing using regolith with a polyethylene additive. The print head will be mountable to a large robot arm to print a 1 meter diameter dome, similar to what might be needed for construction of a moon or Mars base habitat. The building material and the printed structure will be tested for strength properties.

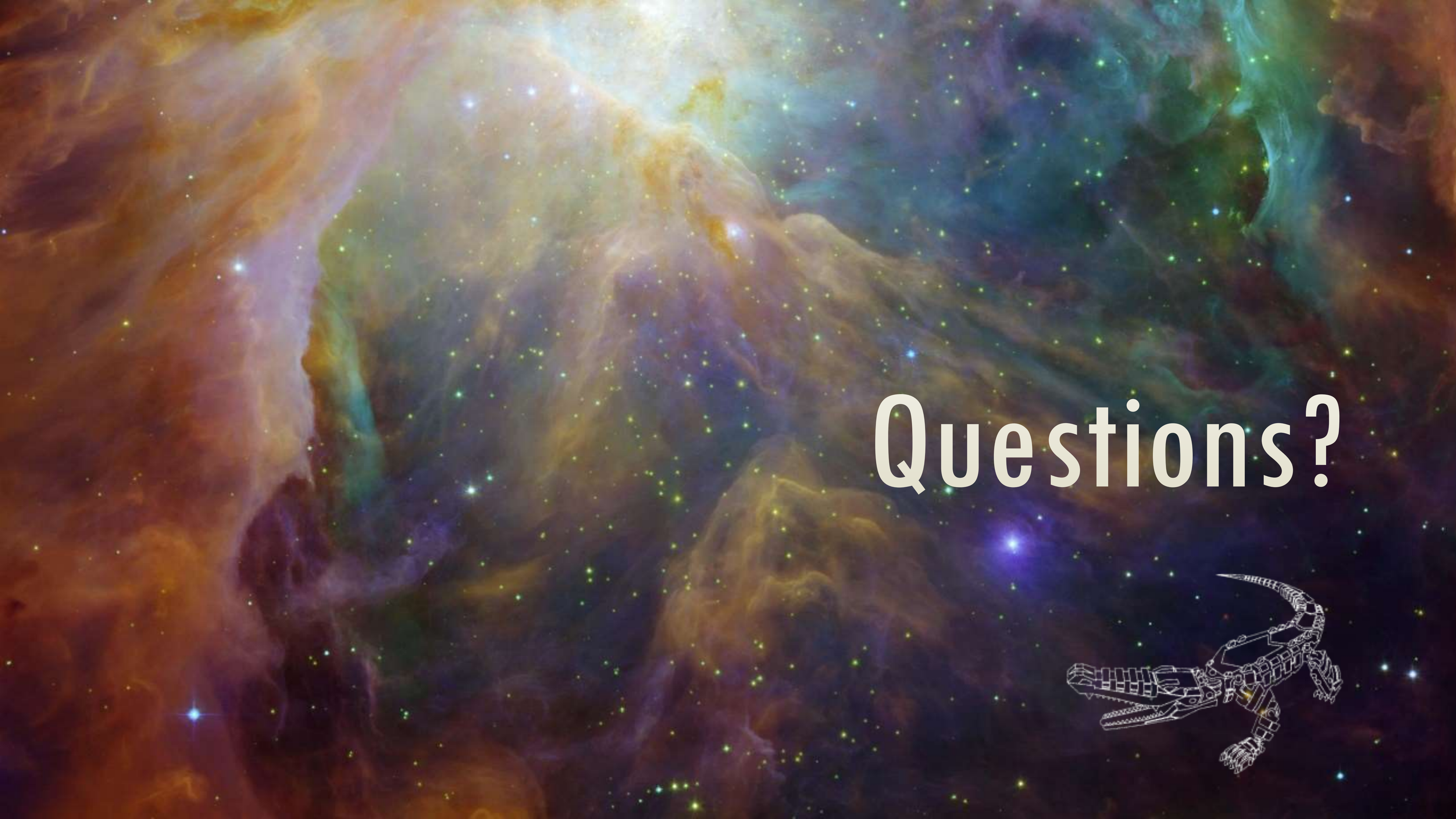


Computer model of robotic arm

Mixing a batch of BP-1 (simulated lunar regolith) with polyethylene

Prototype blocks

Flexural strength testing


Questions?